SALMONIDS IN AN URBAN STREAM: MOVEMENT, HABITAT, AND POTENTIAL BARRIERS

Connor Thomas Parrish
connor.parrish1988@gmail.com

Follow this and additional works at: https://digitalcommons.cwu.edu/etd
Part of the Aquaculture and Fisheries Commons

Recommended Citation
Parrish, Connor Thomas, "SALMONIDS IN AN URBAN STREAM: MOVEMENT, HABITAT, AND POTENTIAL BARRIERS" (2017). All Master’s Theses. 768.
https://digitalcommons.cwu.edu/etd/768

This Thesis is brought to you for free and open access by the Master’s Theses at ScholarWorks@CWU. It has been accepted for inclusion in All Master's Theses by an authorized administrator of ScholarWorks@CWU. For more information, please contact pingfu@cwu.edu.
SALMONIDS IN AN URBAN STREAM:
MOVEMENT, HABITAT, AND POTENTIAL BARRIERS

A Thesis
Presented to
The Graduate Faculty
Central Washington University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Biological Sciences

by
Connor Thomas Parrish
December 2017
CENTRAL WASHINGTON UNIVERSITY

Graduate Studies

We hereby approve the thesis of

Connor Thomas Parrish

Candidate for the degree of Master of Science

APPROVED FOR THE GRADUATE FACULTY

__________________________
Dr. Paul James, Committee Chair

__________________________
Dr. Clay Arango

__________________________
Dr. Daniel Beck

__________________________
Dean of Graduate Studies
Studies on the movement of salmonids in the Pacific Northwest have been vital to their management and recovery. Salmonids can move great distances in search of food, habitat and potential mates, requiring them to travel through a range of different habitat types. Altered and degraded streams may restrict native salmonid use and access to habitat within or beyond urban areas. Locally, restoring native salmonids to streams in urbanized areas is of interest to recovery efforts. However, there is a lack of information in the literature on how salmonids use and navigate urbanized streams. This study used Passive Integrated Transponders (PIT-tags) to monitor the movement and habitat use of two salmonid species (*Salvelinus fontinalis* and *Oncorhynchus mykiss*) in an urban section of Wilson Creek, located in Ellensburg, Washington. Salmonids ranged in length from 72-256 mm and were observed over an eight month period. A 710 m study site included five fragmented sections of open stream, separated by five buried stream sections of varying lengths. Salmonid activity varied seasonally, and individual movement ranged from 0 - 700
m over the course of the study. The results of this study demonstrated that most low gradient buried steam sections were navigable by salmonids. However, large buried sections of stream impede the movement of salmonids. Additionally, habitat quality was assessed within the five open stream sections, which ranged from highly degraded, channelized areas to a restored meandering section. Data on salmonid densities and the diversity of the fish community demonstrate that small scale restoration projects can benefit the aquatic community.
ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Paul James, for his assistance and support throughout this process. I am also thankful for the help that I received from my other committee members, Dr. Clay Arango and Dr. Daniel Beck. I am very appreciative of my fellow graduate students for their support, especially Chas Lawson, Brandon Rossi, Corey Brumbaugh, and Kayleigh Mullen, who assisted with data collection. Additionally, the entire staff of the biology department was incredibly helpful and supportive during my time at Central Washington University. I am also grateful to the School of Graduate Studies for awarding me a grant that helped cover the cost of my equipment.

Multiple biologists from local agencies were extremely accommodating during my project and deserve acknowledgement. This includes Zack Mays of Yakama Nation Fisheries, who helped me construct PIT tag antennas and allowed me to borrow equipment. In addition, Ryan Steele from WDFW assisted with fish capture and Gabe Temple of WDFW who loaned equipment to this study and shared historic data on Wilson Creek.

My family was instrumental in fostering and encouraging my love for the outdoors, especially my parents Chris and Ted, sister Niki, my uncle Stan, and grandfather. Finally, I am forever indebted to my wife, Ashton Bunce, for her support, patience and assistance over the past two years.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Salmonids</td>
<td>1</td>
</tr>
<tr>
<td>The Decline of Salmonids in the Pacific Northwest</td>
<td>2</td>
</tr>
<tr>
<td>Urbanization of Streams</td>
<td>3</td>
</tr>
<tr>
<td>Urban Stream Revitalization</td>
<td>4</td>
</tr>
<tr>
<td>Objectives</td>
<td>5</td>
</tr>
<tr>
<td>II Study Area</td>
<td>6</td>
</tr>
<tr>
<td>Wilson Creek Drainage</td>
<td>6</td>
</tr>
<tr>
<td>Historical Land Uses</td>
<td>8</td>
</tr>
<tr>
<td>Salmonid Recovery</td>
<td>10</td>
</tr>
<tr>
<td>Study Organisms</td>
<td>11</td>
</tr>
<tr>
<td>III METHODS</td>
<td>14</td>
</tr>
<tr>
<td>Study Site</td>
<td>14</td>
</tr>
<tr>
<td>Fish Capture</td>
<td>15</td>
</tr>
<tr>
<td>Movement</td>
<td>17</td>
</tr>
<tr>
<td>Potential Movement Barriers</td>
<td>18</td>
</tr>
<tr>
<td>Seasonal Activity</td>
<td>18</td>
</tr>
<tr>
<td>Habitat Association</td>
<td>19</td>
</tr>
<tr>
<td>Density and Diversity</td>
<td>19</td>
</tr>
<tr>
<td>Descriptive Habitat</td>
<td>20</td>
</tr>
<tr>
<td>IV RESULTS</td>
<td>21</td>
</tr>
<tr>
<td>Fish Sampling</td>
<td>21</td>
</tr>
<tr>
<td>Density and Diversity</td>
<td>24</td>
</tr>
<tr>
<td>Descriptive Habitat</td>
<td>26</td>
</tr>
<tr>
<td>Habitat Association</td>
<td>29</td>
</tr>
<tr>
<td>Recapture Statistics</td>
<td>31</td>
</tr>
<tr>
<td>Seasonal Activity</td>
<td>33</td>
</tr>
<tr>
<td>Potential Movement Barriers</td>
<td>35</td>
</tr>
</tbody>
</table>
## TABLE OF CONTENTS (CONTINUED)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td>37</td>
</tr>
<tr>
<td><strong>V</strong> DISCUSSION</td>
<td>41</td>
</tr>
<tr>
<td>Temperature and Growth</td>
<td>42</td>
</tr>
<tr>
<td>Habitat Quality</td>
<td>43</td>
</tr>
<tr>
<td>Movement</td>
<td>44</td>
</tr>
<tr>
<td>Movement Barriers</td>
<td>45</td>
</tr>
<tr>
<td>Anadromous Salmonids in Wilson Creek</td>
<td>46</td>
</tr>
<tr>
<td>Salmonid Recovery in the Upper Yakima Basin</td>
<td>48</td>
</tr>
<tr>
<td>Management Implications</td>
<td>51</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>53</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>60</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average salmonid growth by size class within the Wilson Creek study area</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>Density of salmonids in each section of open stream within the Wilson Creek study area</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Summary of descriptive habitat variables for each open section of the Wilson Creek study area; 5 indicates the highest rating with 1 indicating the lowest. Section 1 was restored in 2009 to benefit the aquatic community and received the highest average rating for all descriptive habitat variables</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>Data collected at each buried stream section within the Wilson Creek study area. Measurements were collected to characterize buried sections and predict potential salmonid passage</td>
<td>35</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A map of the Wilson Creek watershed in Kittitas County, Washington. Wilson Creek drains an area of ~1,023 km² with an average annual precipitation of 40.13 cm.</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Adult a) rainbow trout and b) brook trout from Wilson Creek. The brook trout was captured post spawning season, resulting in its slender appearance.</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>The study area on the West Branch of Wilson Creek located on the campus of Central Washington University, Ellensburg, WA.</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>The number of salmonids PIT-tagged per section of open stream within the Wilson Creek study area.</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>In Wilson Creek 92 brook trout and 12 rainbow trout were PIT-tagged.</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>Frequency of salmonids tagged in Wilson Creek by age class. 21 YOY salmonids &lt;101 mm FL and 83 Adult/Juvenile salmonids &gt;101 mm FL.</td>
<td>23</td>
</tr>
<tr>
<td>7</td>
<td>Fork lengths of salmonids at time of tagging in Wilson Creek study area.</td>
<td>24</td>
</tr>
<tr>
<td>8</td>
<td>Species of fish collected in each section of open stream within the Wilson Creek study area.</td>
<td>26</td>
</tr>
<tr>
<td>9</td>
<td>Upstream photographs of open sections 1-5 within Wilson Creek study area.</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>Habitat associated with salmonid observations compared to their expected locations within the available habitat of Wilson Creek: (A) adult/juvenile (df = 2, ( \chi^2 = 16.61, p = 0.0002 )) and (B) YOY salmonids (df = 2, ( \chi^2 = 5.43, p = 0.0663 )). Confirming the importance of pool habitat to adult/juvenile salmonids in urban streams.</td>
<td>31</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>The number of PIT-tagged salmonids observed during day and night portable antenna surveys within the Wilson Creek study area. Night surveys yielded statistically higher recaptures than day surveys (two sample $t = -3.088$, df = 29, $p = 0.0044$) ........................................ 32</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Seasonal activity of PIT-tagged salmonids in Wilson Creek described by unique monthly stationary antenna hits with A) weekly streamflow (m$^3$/s) and B) average daily stream temperature °C ........................................ 34</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Photographs of the downstream end of buried sections 1-5 within the Wilson Creek Study area ........................................................................................................ 36</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>The frequency and directionality of movement by PIT-tagged salmonids through buried sections of stream within the Wilson Creek study area. Buried section 1 appears to be a barrier to the upstream movement of salmonids ........................................................................................................ 37</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>The range of movement of PIT-tagged salmonids within the Wilson Creek study area from June 10th through January 23rd (N = 95 Min = 0.0 Max = 700 Median = 65.0 Mean = 86.9) ............................. 38</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>The relationship between length and range of movement of PIT-tagged salmonids within the Wilson Creek study area. This was likely influenced by the 300 m buried section that prevent the upstream movement of salmonids .................................................................................................................................................. 39</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>The distance between first and last detection of PIT-tagged salmonids within the Wilson Creek study area. Demonstrating that salmonids were able to move both up and downstream throughout most of the study area ....... 40</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>LWD located in open sections of stream within the Wilson Creek study area. All LWD pieces had a minimum length ≥ 1 m and a diameter ≥ 10 cm .......................................................................................................................................................... 60</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Average fish cover for each open section of stream within the Wilson Creek study area. Fish cover elements included woody debris, overhanging x</td>
<td></td>
</tr>
</tbody>
</table>
vegetation, aquatic vegetation and artificial fish cover ........................................ 60

20 Substrate composition estimations for each open section of stream within the Wilson Creek study area .......................................................... 61

21 Percent canopy cover for each open section of stream within the Wilson Creek study area .......................................................... 61

22 Sinuosity rating for each section of open stream within the Wilson Creek study area; higher sinuosity ratings indicates greater channel complexity .......................................................... 62

23 The percent of channel unit type occurring in each section of open stream within the Wilson Creek study area ........................................ 62
I

INTRODUCTION

Salmonids

Salmonids include species of salmon, trout, and char from the family Salmonidae that inhabit cold lakes, streams, and oceans where they primarily feed on invertebrates and other fish species (Behnke 2002). They require freshwater to spawn and exhibit a variety of life history types, including anadromous species that die shortly after spawning, a vital process that provides large quantities of nutrients to aquatic and terrestrial ecosystems (Behnke 2002). Considered a foundation species, salmonids are a food source for countless species of invertebrates, birds, fish, and mammals (Berkson 1999). In the Pacific Northwest, salmonids also provided a dependable year-round food source for thousands of Native Americans (National Research Council 1996). The Columbia River alone once received returns of 8-10 million anadromous salmonids each year prior to European contact (National Research Council 1996).

In the Pacific Northwest, salmonids are of ecological, recreational, cultural, and economic importance (National Research Council 1996; The Federal Caucus 2000; NMFS 2016). This importance has led to an abundance of research on salmonids, to preserve and recover various species. Much of this research has been focused on the movement of salmonids and the importance of connectivity to quality habitat. Salmonids with migratory life histories, such as anadromous Pacific salmon, may travel thousands of kilometers over the course of their lives (Behnke 2002). Similarly, resident salmonids may spend their entire lives within a small home range or travel great distances through a variety of habitat types (Hilderbrand and Kershner 2000; Behnke 2002; James 2014). Salmonids use
different habitat for cover, forage, spawning and rearing. Damaging or restricting access to this habitat can negatively affect salmonid populations (Childs et al. 1998; Letcher et al. 2007; Burford et al. 2009; Poplar-Jeffers et al. 2009; Chelgren and Dunham 2015).

The Decline of Salmonids in the Pacific Northwest

Salmonids are in decline throughout most of their native range and the issues associated with their decline are as numerous as they are complex. Over the past two centuries, Pacific salmon and steelhead trout have vanished from roughly 40% of their historic range in California, Idaho, Oregon and Washington (National Research Council 1996). Early European settlers of the Pacific Northwest marveled at the abundance of salmonids when they came to exploit the region’s seemingly endless resources. Small scale harvest of salmonids eventually gave way to gillnetting that supplied millions of fish each year to canneries (National Research Council 1996). Logging and mining operations destabilized soil, adding fine sediment to streams that smothered spawning gravel (National Research Council 1996). Dredging and massive log drives scoured streambeds destroying critical habitat (National Research Council 1996; McIntosh et al. 2000). Livestock grazing devastated riparian areas and eroded streambanks, degrading stream habitat and increasing sediment inputs (National Research Council 1996). Dams for flood prevention, logging, irrigation and hydroelectric power altered stream habitat and impeded or completely blocked salmonid migrations (National Research Council 1996; Waples et al. 2008). Streams were channelized or redirected for flood prevention, land development and the transportation of water, people, and goods (National Research Council 1996). As the human population grew, pollutants, toxicants and land development
associated with anthropogenic activities further degraded streams of the Pacific Northwest (National Research Council 1996; Walsh et al. 2005). Currently, these activities are highly regulated; however, their legacy continues to challenge native salmonids (McIntosh et al. 2000).

**Urbanization of Streams**

The growth of urban landscapes has had detrimental effects on stream habitat (Walsh et al. 2005). Throughout the Columbia Basin, streams have been channelized, rerouted and even forced underground. Habitat alteration and fragmentation can reduce the diversity and density of native fish communities and limit their movement (Pépino et al. 2012; Edge et al. 2016). Buried sections of stream can create barriers to fish, often restricting access to upstream habitat (Hoffman and Dunham 2007; Poplar-Jeffers et al. 2009; Pépino et al. 2012; Tortonot et al. 2014). This can result in habitat loss and a reduction of gene flow and genetic diversity in salmonid populations located upstream of barriers (Wofford et al. 2005; Hoffman and Dunham 2007; Letcher et al. 2007; Rosenberger et al. 2012; Tortonot et al. 2014). Impervious surfaces, such as roads and sidewalks, have resulted in highly variable streamflow (Walsh et al. 2005). Water and pollutants are delivered across these impermeable surfaces, through storm drains and into streams (Walsh et al. 2005; Meyer et al. 2005). The reduction of riparian areas decreases terrestrial organic matter inputs, alters food web process, diminishes the ability of streams to store water, and reduces the uptake of nutrients such as nitrogen and phosphorous (Lowrance et al. 1984; Groffman et al. 2003; Walsh et al. 2005; Beaulieu et al. 2014). In addition, the removal of riparian vegetation reduces shading, increases solar radiation, and hinders
natural recruitment of large woody debris (LWD) (Groffman et al. 2003; Walsh et al. 2005; Horwitz et al. 2008). This results in variable water temperatures and a decline in habitat complexity (Groffman et al. 2003; Walsh et al. 2005; Horwitz et al. 2008). Channelization of streams increases average streamflow and reduces both sinuosity and instream habitat complexity (Hollis 1975; Walsh et al. 2005). The combination of these factors has been described as “the urban stream syndrome”, which can have extremely detrimental effects on native fish populations (Ourso and Frenzel 2003; Regetz 2003; Walsh et al. 2005).

Urban Stream Revitalization

Despite the severe alteration and degradation of urban streams, there is a growing body of literature supporting their potential value to both human and aquatic communities (Heggenes and Traaen 1998; Buchholz and Younos 2007; Poplar-Jeffers et al. 2009; Wild et al. 2011). Restoration of urban streams has become more common during the past few decades; daylighting buried sections of stream, replacing culverts, restoring riparian areas, installing LWD, and creating channel complexity in urban streams has helped restore natural ecological functions (Cederholm and Bilby 1997; Roni and Quinn 2001; Bernhardt and Palmer 2007; Roni et al. 2008; Wild et al. 2011). These projects have the added benefit of creating green spaces for the public to enjoy and generating awareness of the importance of natural ecosystems (Buchholz and Younos 2007; Wild et al. 2011).

In the Pacific Northwest, agencies tasked with the management of salmonid populations have expressed interest in restoring urban streams to aid in recovery efforts (Hubble 2004; Conley et al. 2009). However, further research is needed on how fish use urban streams. In fact, the effect of urbanization on the movement of aquatic organisms has
been listed as one of 26 key research areas in urban stream ecology (Wenger et al. 2009). This lack of knowledge on the movement of salmonids and the effectiveness of habitat restoration in urban streams should be addressed prior to investing significant resources.

Objectives

The objective of this study was to determine the movement patterns and habitat use of salmonids in an urban stream to aid in future recovery efforts. To determine the movement of salmonids, I 1) monitored the movement of brook and rainbow trout in a small urban stream over a period of eight months; 2) assessed the ability of these salmonids to navigate potential movement barriers; and 3) documented changes in their seasonal activity. To characterize urban stream habitat and assess the usefulness of a restoration project, I 1) compared habitat used by salmonids to the habitat available to them in an urban stream; 2) compared the density and diversity of fishes in fragmented sections of stream; and 3) collected auxiliary data on streamflow, substrate composition, stream temperature, LWD, canopy cover, fish cover, and sinuosity.
II

STUDY AREA

Wilson Creek Drainage

Wilson Creek is located in the center of Washington State within the Yakima River Basin, near the city of Ellensburg, in Kittitas County (Figure 1). Wilson Creek is a third-order stream that originates from Colockum Ridge at 1,973 m above mean sea level (AMSL) on the eastern slope of the Cascade Mountains and flows south to its confluence with the Yakima River at 433 m AMSL. Wilson Creek is a snowmelt driven system that drains an area of ~1,023 km² with an average annual precipitation of 40.13 cm (U.S. Geological Survey 2012).

Wilson Creek begins as a high gradient stream in the Okanogan-Wenatchee National Forest where it flows for ~13 km through a timbered canyon of ponderosa pine and Douglas-fir before merging with Naneum Creek. It then travels ~2.5 km before separating into Whiskey Creek, Mercer Creek, Naneum Creek and Wilson Creek as it spreads across an alluvial fan. Wilson Creek subsequently flows for ~11.5 km through shrub-steppe and agricultural lands until it splits once more into the East and West Branches as it enters the city of Ellensburg. Each branch travels ~4 km until they meet again on the south side of town. The creek continues another ~12.5 km through agricultural fields as it receives water from five different creeks and multiple irrigation canals before reaching the Yakima River.
Figure 1. A map of the Wilson Creek watershed in Kittitas County, Washington. Wilson Creek drains an area of ~1,023 km² with an average annual precipitation of 40.13 cm.
Historic Land Uses

Prior to settlement by Euromericans, the land encompassing Kittitas County was used by the Yakama Nation (County Centennial Committee Kittitas 1989). Native people gathered here to trade, hunt, collect camas, and harvest salmon (County Centennial Committee Kittitas 1989). At one time, Wilson Creek was a traditional location of salmon harvests, where fish were caught with traps made of woven willow branches and eaten fresh or dried to be stored for later use (County Centennial Committee Kittitas 1989).

Early settlers arrived in the 1860s and found a valley of unexploited natural resources. Sawmills were first constructed in the 1870s and were supplied by logging camps throughout the upper Yakima basin (County Centennial Committee Kittitas 1989; Caveness 2012). Mining took off during the late 1800s with the discovery of coal in 1881 and several successful gold claims on tributaries of the Yakima River (County Centennial Committee Kittitas 1989; Caveness 2012). Thousands of cattle and sheep were grazed in the valleys and headwaters of Kittitas County before being led over Snoqualmie Pass to sell in Seattle (County Centennial Committee Kittitas 1989; Caveness 2012). Each of these activities helped support the economy and establish the town of Ellensburg.

Additionally, the fertile soil of Kittitas County was ideal for growing crops, which created demand for water. Irrigation initially consisted of primitive ditches diverting streams for watering crops (County Centennial Committee Kittitas 1989; Tuck 1995). As time went on, entire stream channels were rerouted and irrigation dams were constructed to deliver water through a network of irrigation canals (County Centennial Committee Kittitas 1989; Tuck 1995). Besides the direct impact of degrading stream habitat, irrigation canals attracted salmonids, which became trapped and perished at the end of irrigation
season (Tuck 1995). Early irrigation dams often lacked or had poorly designed fish passage that blocked the upstream migration of salmonids (Tuck 1995; Conley et al. 2009). In the early 1900s, three large storage reservoirs were constructed in the upper Yakima basin that blocked the movement of migratory salmonids and severely altered seasonal streamflow (Tuck 1995).

The stream habitat of Wilson Creek was further degraded by urbanization. As early as 1897, the stream was buried as it traveled under the campus of Central Washington University (Sanborn Map Company 1897). Another early account of alteration of Wilson Creek occurred in 1923, when hundreds of volunteers helped excavate a new channel to make room for the Ellensburg Rodeo Fairgrounds (County Centennial Committee Kittitas 1989; Caveness 2012). Overtime, increased development and the construction of roadways completely reshaped the lower reaches of Wilson Creek.

Furthermore, this urbanization degraded and fragmented stream habitat which negatively affected native fish. Wilson Creek once supported native runs of anadromous summer steelhead trout (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) (Hubble 2004; Conley et al. 2009). It is likely that Wilson Creek also supported resident and fluvial populations of cutthroat trout (*O. clarkii*), rainbow trout (*O. mykiss*) and bull trout (*Salvelinus confluentus*). Currently, the occasional spawning and rearing by anadromous salmonids is restricted to the lower reaches of Wilson Creek (Conley et al. 2009). Native cutthroat are restricted to the headwaters of Wilson Creek, while the middle reaches are inhabited by low numbers of resident rainbow trout and an abundance of eastern brook trout (*Salvelinus fontinalis*) (James et al. 2014; Arango et al. 2015; email from Temple 2017).
Salmonid Recovery

In the Yakima basin, exploitation of natural resources and declines of native salmonids have given way to management and recovery efforts. Logging, mining, and fishing practices have been reduced and regulated, while irrigation channels have been screened and water releases from reservoirs have been altered to benefit salmonids. Many fish passage barriers have been removed or improved, allowing salmonids to access historic habitat (Conley et al. 2009; Yakama Nation Fisheries 2014; Monk 2015). This has resulted in increased returns of spring chinook and steelhead to the upper Yakima River, and the return of two extirpated species, sockeye (*Oncorhynchus nerka*) and coho salmon (Hubble 2004; Conley et al. 2009; Yakama Nation Fisheries 2014). However, many challenges to recovery remain and anadromous salmonid returns continue to be a shadow of their former selves (Ackerman et al. 2002; Yakama Nation Fisheries 2014).

Local recovery plans for the upper Yakima basin have identified urban streams in Kittitas County as potential areas to continue recovery efforts for coho salmon and steelhead trout (Hubble 2004; Conley et al. 2009; NOAA Fisheries 2016). There are many hurdles to restoring native anadromous salmonids to these streams including issues related to fragmented and degraded habitat, potential movement barriers, altered streamflow, water quality and potential temperature issues (Hubble 2004; Conley et al. 2009; NOAA Fisheries 2016). Before investing significant resources for urban habitat restoration and reintroduction of native salmonids, more research is necessary to evaluate the feasibility of local recovery projects.

Urban streams may be used by salmonids and provide access to higher quality habitat located in the upper reaches of these streams (Hubble 2004; Conley et al. 2009). In
2012, one study by James et al. evaluated fish passage in two urban streams that flow through Ellensburg. Thousands of hatchery reared juvenile coho were stocked in Wilson and Mercer Creeks and tracked over a period of 11 months. Coho were documented successfully navigating buried sections of stream in the downstream direction, 6.6% of which were observed at main stem Columbia River dams (James 2014). However, no live fish were observed moving upstream through buried stream sections (James 2014). Due to the lack of upstream movement, questions remained about how potential movement barriers caused by buried stream sections could prevent recovery efforts in urban streams (James 2014). These results indicated that further investigation is needed to examine how salmonids use urban streams.

Study Organisms

Despite current and historic land use practices and urbanization, Wilson Creek supports populations of two salmonids within the city limits of Ellensburg. The presence of rainbow trout and invasive eastern brook trout indicate that this urban ecosystem can sustain salmonid populations (Figure 2). Studying these two species can provide insight into how native salmonids could use urban streams.
Figure 2. Adult a) rainbow trout and b) brook trout from Wilson Creek. The brook trout was captured post spawning season, resulting in its slender appearance.

Rainbow trout are native to Wilson Creek; however, they were often stocked for youth fishing derbies, adding uncertainty to their origin (Personal communication with James 2017). Rainbow trout spend their entire lives in freshwater, unlike their anadromous counterparts, steelhead trout (Raleigh et al. 1984). Ideal rainbow trout habitat consists of streams with an abundance of cover and a 1-1 pool-to-riffle ratio (Raleigh et al. 1984). Rainbow trout heavily use pools for rest and cover, but move into riffles to feed and spawn (Raleigh et al. 1984). Well oxygenated water between 0 – 25 °C is required by rainbow trout, with an optimal temperature range of 12 – 18 °C (Raleigh et al. 1984). Rainbow trout spawn during the spring in riffles and pool tails in loose, silt-free, well oxygenated gravel (Raleigh et al. 1984).

Eastern brook trout are native to the cold waters of eastern North America (Raleigh 1982). The popularity of brook trout as a game fish has resulted in their introduction
throughout North America (Raleigh 1982). Brook trout are primarily a freshwater species; however, anadromy occurs in coastal regions where they have access to the ocean (Raleigh 1982). Brook trout populations are most stable in streams with a 1-1 pool-to-riffle ratio, ample cover, and deep, low velocity water (Raleigh 1982). Brook trout can inhabit water from 0 – 24 °C, with a preferred temperature range of 11 – 16 °C. Spawning occurs during the fall in silt-free, well-oxygenated gravel of riffles, pool tails, or lakes (Raleigh 1982).

Many of the similarities between brook trout and rainbow trout are also shared with other native salmonids. While each species has unique spawning requirements and life histories, they all require cold, clean water and complex habitat, indicating that studies on any one species can provide insight for other closely related salmonids (Sullivan et al. 2000; Behnke 2002). The presence of rainbow and brook trout in Wilson Creek presented a unique opportunity to study the natural movement and habitat use of salmonids in an urban stream.
III

METHODS

Study Site

The study site is a 710 m section of the West Branch of Wilson Creek, which runs through the southeast corner of Central Washington University's campus (Figure 3). Within this study area, there are five sections of open stream measuring approximately 120 m, 46 m, 80 m, 50 m and 18.5 m in length. The 120 m section was once a concrete channel running between two university dormitories that was restored in 2009, creating a park and benefiting the aquatic ecosystem (Arango et al. 2015). Separating the open sections are five buried sections of stream, approximately 300 m, 30 m, 15 m, 24.5 m and 26 m in length. The five open sections of stream were divided into ~10 m segments. Each segment was flagged and labeled sequentially with a unique identifier.
Figure 3. The study area on the West Branch of Wilson Creek located on the campus of Central Washington University, Ellensburg, WA.

**Fish Capture**

At each segment of open stream, all species of fish were collected using a Smith Root® backpack electrofisher and placed in a 5-gallon bucket. I operated the electrofisher, while 2-3 assistants used dipnets to collect fish. A solution of Tricaine Methanosulfonate (MS-222) was used to sedate fish for handling, identification, measuring and tagging.
Salmonids greater than 70 mm in fork length (FL) were tagged with 12 mm passive integrated transponder (PIT) tags using a Biomark® PIT-tag implanter. Each PIT-tag had a unique alphanumeric code that allowed for the tracking of individual fish. All PIT-tag codes, FL measurements, and capture locations were recorded in a field notebook. Additionally, all non-target fish species were identified and recorded. After tagging, fish were allowed to recover before they were released back into the same 10 m segment of open stream where they were collected.

Two fish capture events were required to tag adult/juvenile and young-of-the-year (YOY) salmonids. The initial fish capture event on June 10th, 2016, resulted in the tagging of adult/juvenile brook trout and rainbow trout. YOY are salmonids that are less than a year old and exhibit unique behavior compared to more mature adult/juvenile fish. Their unique behavior due to their smaller size and reduced swimming ability is of interest to this study. Data collected on YOY brook trout would provide insight to how native YOY salmonids would fare in Wilson Creek, especially Coho which spawn around the same time of year as brook trout (Einum and Nislow 2005). During the first fish capture event, 26 of 28 YOY brook trout collected measured <70 mm FL. Due to the >70 mm tagging threshold, I collected and tagged additional salmonids on July 28th, 2016, which allowed the YOY age class time to reach an appropriate size for tagging.

A final fish capture event was conducted using the electrofisher on January 23rd, 2017 to obtain the end location of tagged salmonids and acquire lengths of tagged fish to evaluate growth over the course of the study. This capture event was conducted in the same manner as previous capture events with the exception that no new salmonids were
PIT-tagged. All capture and handling of fish was approved by the Central Washington University Institutional Animal Care and Use Committee (IACUC protocol #A11507)

**Movement**

To monitor tagged fish which emigrated or returned to the study site, two fixed, custom-built PIT-tag antennas were installed at the top and bottom of the study site. Each of these 3 m by 1 m antennas were equipped with an Allflex® reader powered by two 6-Volt batteries. Each week the top and bottom of site PIT-tag antennas were downloaded to identify any tagged fish which had exited or returned to the study site.

Within the study area, a portable handheld Biomark® antenna was used to manually track individual fish, with a read range of 10-15 cm. The portable antenna was held just above the surface of the water or submerged to locate PIT-tagged salmonids. Recapture surveys using this antenna were conducted each week and alternated between day and night surveys.

Net movement was calculated using the initial and final observation locations of each salmonid, providing data on the directionality of individual salmonid movements and incidences of site fidelity. Total range of movement was calculated based on the furthest upstream and downstream observation of each fish during the study. Spearman’s rank correlation was used to analyze the relationship between salmonid length and range of movement during the study ($\alpha=0.05$).
Potential Movement Barriers

Within the study area, Wilson Creek is forced underground through culverts at five buried sections. At each buried section, the type of culvert was identified according to an assessment protocol created by the Washington State Department of Fish and Wildlife (Washington Department of Fish & Wildlife 2009). Data was collection on culvert type, slope, diameter, length and the presence of streambed material (Washington Department of Fish & Wildlife 2009). The results of these surveys help identify physical characteristics of buried stream sections that may inhibit the upstream movement of salmonids. If this information could not be collected in the field, it was documented as unknown.

Tagged fish cannot be detected while under a buried section of stream. Movement of fish through buried sections could only be evaluated when salmonids were recaptured after moving through the entirety of a buried section. This data was used to assess which buried sections might directionally bias fish movement or restrict their movement at different age classes.

Seasonal Activity

Only a portion of the PIT-tagged salmonids were observed during each portable antenna survey, therefore the time between observations of individual fish was highly variable. Because of this, it was difficult to observe seasonal activity of salmonids. The best indication of seasonal activity was the number of individual fish that were detected on the top and bottom of site PIT-tag antennas. Monthly detections were combined and sorted; duplicate tag codes were then removed to obtain individual salmonid detections per
Habitat Association

Habitat availability data was collected through channel unit surveys following sampling procedures detailed in the Columbia Habitat Monitoring Program (CHaMP) protocol, which was scaled to meet the needs of the study design (Columbia Habitat Monitoring Program 2014). Within each 10 m segment of open stream, the proportion of each channel unit type present and the dominant channel unit type was recorded.

This data was used to describe habitat associated with salmonid use within the study area. All salmonids captured during electrofishing surveys were assigned to the 10 m segment of open stream from which they were caught. The dominant channel unit associated with that segment was then recorded as the channel unit type used by each individual fish. A chi-squared goodness-of-fit test was performed to compare the proportion of habitat available to the habitat used to determine habitat associations for YOY and adult/juvenile age-classes.

Density and Diversity

The initial fish capture event occurred when the water level, water clarity, and stream and air temperatures were optimal for collecting and handling all species of fish. Salmonid densities per meter were calculated by dividing the number of fish collected in each open section by the length of the section. For each of the five open sections of stream, diversity was calculated using the Shannon Diversity Index:

\[ H^1 = \sum_{i=1}^{S} P_i \ln P_i \]
Where $H^1$ is the Shannon diversity index, $P_i$ is the fraction of the population which is made up of species $i$, and $S$ is the number of species collected.

**Descriptive Habitat**

Streamflow measurements were taken each week at the top and bottom of the study area using a Hach FH 950.1 handheld flow meter. Readings from the two locations were averaged to obtain a single measurement. HOBO pendant temperature loggers were attached to rebar and installed at the top and bottom of the study area. Stream temperature was recorded hourly during the study. Habitat surveys for LWD, channel units, substrate composition and fish cover were conducted at each 10 m section of open stream using methods described by the CHaMP protocol (Columbia Habitat Monitoring Program 2014). Canopy cover was also collected at the center of each 10 m segment using a spherical concave densiometer and following a protocol detailed by the Washington State Department of Ecology (Werner 2009). Sinuosity, often used as a measure of channel complexity, was calculated for the five open sections using the following equation (Rosgen 1994).

\[
\text{Sinuosity} = \frac{\text{Channel Length}}{\text{Straight Line Distance}}
\]
IV

RESULTS

Fish Sampling

Two electrofishing events on June 10th and July 28th, 2016 resulted in the PIT-tagging of 104 salmonids, the majority of which were collected from section 1 (Figure 4). Salmonids found in Wilson Creek were primarily brook trout, with the exception of 12 rainbow trout (Figure 5). Of the 104 tagged fish, 21 were YOY brook trout and the other 83 fish were grouped together as adult/juvenile salmonids (Figure 6). At the time of tagging, salmonids ranged from 72 to 254 mm FL, with YOY ranging from 72 to 101 mm FL (Figure 7). The final electrofishing event on January 23rd, 2017 resulted in the collection of 45 salmonids, 22 of which were recaptures. Of the recaptured salmonids, YOY had the largest average growth of any size class over the length of the study (Table 1). With an average FL of 62.9 mm on June 10th, YOY were too small to tag during the initial electrofishing event. The average length of all YOY on January 23rd was 125.9 mm, resulting in an average growth of 63 mm.
Figure 4. The number of salmonids PIT-tagged per section of open stream within the Wilson Creek study area.

Figure 5. In Wilson Creek, 92 brook trout and 12 rainbow trout were PIT-tagged.
Figure 6. Frequency of salmonids tagged in Wilson Creek by age class. 21 YOY salmonids <101 mm FL and 83 Adult/Juvenile salmonids >101 mm FL.
**Figure 7.** Fork length of salmonids at time of tagging in Wilson Creek study area.

**Table 1:** Average salmonid growth by size class within the Wilson Creek study area. *YOY were first tagged July 28th*

<table>
<thead>
<tr>
<th>FL at Time of Tagging</th>
<th>Average Growth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200+</td>
<td>5.2</td>
</tr>
<tr>
<td>102-199</td>
<td>15.3</td>
</tr>
<tr>
<td>72-101 (YOY)*</td>
<td>35.6</td>
</tr>
</tbody>
</table>

**Density and Diversity**

Salmonid densities per meter were highest in sections 1 and 4, whereas sections 2, 3, and 5 had substantially lower densities (Table 2). Seven species of fish were captured during the electrofishing survey. This included 6 native species; rainbow trout, speckled dace (*Rhinichthys osculus*), brook lamprey (*Lampetra richardsoni*), bridgelip sucker (*Catostomus columbianus*), redside shiner (*Richardsonius balteatus*), and sculpin spp. (*Cottus spp.*). Eastern brook trout were the only invasive species present in the study area. Section 1 had 7 species of fish present, while no other section contained more than 4
species (Figure 8). The Shannon diversity index revealed that section 1 had the highest diversity rating (diversity rating by section– 1: 1.35, 2: 1.03, 3: 0.95, 4: 0.87, and 5: 0.00).

Table 2. Density of salmonids in each section of open stream within the Wilson Creek study area.

<table>
<thead>
<tr>
<th>Section</th>
<th>Species</th>
<th># of Individuals</th>
<th>Density (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Eastern Brook Trout</td>
<td>45</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Rainbow Trout</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Eastern Brook Trout</td>
<td>5</td>
<td>0.11</td>
</tr>
<tr>
<td>3</td>
<td>Eastern Brook Trout</td>
<td>12</td>
<td>0.15</td>
</tr>
<tr>
<td>4</td>
<td>Eastern Brook Trout</td>
<td>24</td>
<td>0.48</td>
</tr>
<tr>
<td>5</td>
<td>Eastern Brook Trout</td>
<td>2</td>
<td>0.11</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.26</td>
</tr>
</tbody>
</table>
Figure 8. Species of fish collected in each section of open stream within the Wilson Creek study area.

Descriptive Habitat

Habitat data was collected to identify differences in habitat among the five sections of open stream. LWD was defined as any piece of dead woody vegetation that had a length ≥ 1 m and a diameter ≥ 10 cm. LWD was only included in the survey if a portion of it was within the bankfull channel. In 2009, section 1 had log structures installed to benefit the aquatic ecosystem. Because of this, section 1 had the highest LWD count (Figure 18). Fish
cover was described as the percentage of fish cover elements within 1 m above the surface of the stream. Fish cover elements included woody debris, overhanging vegetation, aquatic vegetation, and artificial fish cover (tires, cement, trash, etc.). The dominant fish cover element within the study area was overhanging vegetation that formed from dense mats of invasive reed canary grass (Figure 19). Canopy cover estimations were variable, with section 3 having a heavily vegetated over story contrasted by section 2, which had no canopy cover (Figure 21). Species contributing to canopy cover included: crack willow (*Salix fragilis*), black cottonwood (*Populus trichocarpa*), ponderosa pine (*Pinus ponderosa*), aspen (*Populus tremuloides*), blue spruce (*Picea pungens*), and walnut (*Juglans ssp.*) trees.

Substrate composition estimates were similar in sections 2-5 where coarse gravel was the most dominate substrate. Section 1 differed from other sections with fine gravel being the most dominant substrate type (Figure 20). Sinuosity calculations for each of the five open stream sections were used as a relative measure of stream complexity. Section 1 and 3 had the highest sinuosity ratings with sections 2, 4 and 5 having ratings near 1, indicating a lack of stream complexity (Figure 22).

Channel unit surveys revealed that pool, non-turbulent, and riffle channel units were the only habitat types found within the study area. Approximately half of the study area was comprised of riffle habitat with the remaining habitat split between pool and non-turbulent channel units. The importance of pool habitat to salmonids has been well documented in the literature (Raleigh 1982; McMahon 1983; Raleigh et al. 1984). The restored stream habitat of section 1 had the highest percentage of pools and highest diversity of habitat types compared to other open sections of stream (Figure 23).
To summarize all descriptive indicators of habitat quality, I rated each open stream section 1-5, 5 indicating the highest and 1 the lowest rating for each category (Table 3). Ratings for each section were averaged together to obtain a rough measurement of overall habitat quality. Section 1 which was restored in 2009, consistently received high scores for each descriptive habitat variable.

Table 3. Summary of descriptive habitat variables for each open section of the Wilson Creek study area; 5 indicates the highest rating with 1 indicating the lowest. Section 1 was restored in 2009 to benefit the aquatic community and received the highest average rating for all descriptive habitat variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Section 1</th>
<th>Section 2</th>
<th>Section 3</th>
<th>Section 4</th>
<th>Section 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>LWD</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Pool</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Fish cover</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Canopy Cover</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Sinuosity</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Length</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Salmonid Density</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Shannon Diversity</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Average</td>
<td>4.38</td>
<td>2.38</td>
<td>3.38</td>
<td>2.63</td>
<td>1.75</td>
</tr>
</tbody>
</table>
During 3 electrofishing surveys in June, July, and January, 97 adult/juvenile and 61 YOY salmonids were collected and associated with the dominant channel unit within their segment of capture. The chi-squared goodness-of-fit test revealed that the habitat associated with the observation of adult/juvenile fish was significantly different than what
was expected based on the habitat available (Figure 10, df = 2, $\chi^2 = 16.61$, p = 0.0002). Adult/juvenile fish were observed more frequently in pool habitat than in non-turbulent and riffle channel units. The chi-squared goodness-of-fit test did not show a significant difference between the expected habitat associations and actual observations of YOY salmonids (Figure 10, df = 2, $\chi^2 = 5.43$, p = 0.0663).

**Figure 10.** Habitat associated with salmonid observations compared to their expected locations within the available habitat of Wilson Creek: (A) adult/juvenile (df = 2, $\chi^2 = 16.61$, p = 0.0002).
p = 0.0002) and (B) YOY salmonids (df = 2, χ² = 5.43, p = 0.0663). Confirming the importance of pool habitat to adult/juvenile salmonids in urban streams.

**Recapture Statistics**

Of the 104 salmonids tagged in June and July 102 of them were recaptured at least once during the study. Stationary antennas at the top and bottom of the study area recorded over 11,000 combined PIT-tag observations of 56 tagged fish. Thirty surveys using the Biomark® portable antenna resulted in 583 PIT-tag observations of 93 tagged fish. These surveys alternated weekly between day and night surveys, with night surveys yielding statistically higher recapture rates than day surveys (Figure 11, two sample t = -3.088, df = 29, p = 0.004)
Figure 11. The number of PIT-tagged salmonids observed during day and night portable antenna surveys within the Wilson Creek study area. Night surveys yielded statistically higher recaptures than day surveys (two sample t = -3.088, df = 29, p = 0.0044).

When live fish were encountered with the portable antenna, they typically registered on the reader and then moved a short distance away. 12 PIT-tags that did not move on repeated surveys, and after sufficient investigation, were documented as shed tags or mortalities. Of these 12, 5 were discovered for the first time in October, during spawning season near spawning gravel. All 5 tags had been implanted in mature fish >170 mm in length, indicating that their appearance may be associated with spawning activity. It has been noted in other salmonid species that females likely expelled their PIT-tags during
spawning (Meyer et al. 2011). Because these 5 fish had been encountered on multiple occasions prior to shedding their tags, they were included in all analyses for this study.

**Seasonal Activity**

Weekly streamflow measurements demonstrated that Wilson Creek remained relatively stable from June through September. In October, Ellensburg received several rain storms which increased Wilson Creek’s streamflow until freezing November air temperatures returned the stream to baseflow (Figure 12). The maximum stream temperature of 21.14 °C was recorded in mid-August with a minimum of 0.45 °C during January (Figure 12).

Monthly antenna detections were combined and sorted before duplicate tag codes were removed to obtain individual salmonid detections per month. The total number of fish detections on stationary antennas peaked in October with 41, which was more than double the number of fish detected on these antennas for any other month during the study. Brook trout spawning activity was first observed during October. This coincided with a decrease in stream temperature and an increase in streamflow caused by multiple rain events (Figure 12). The number of fish detections on stationary antennas were lowest during January, when only 9 individual fish were detected. (Figure 12).
Figure 12. Seasonal activity of PIT-tagged salmonids in Wilson Creek described by unique monthly stationary antenna hits with A) weekly streamflow (m³/s) and B) average daily stream temperature (°C)
Potential Movement Barriers

Buried sections 2-4 were at road crossings and ranged in size from 15 – 30 m in length. The four culverts were similar with a lack of streambed material, low slope measurements, comparable diameters, and construction of corrugated steel (Table 4, Figure 13). I was unable to measure slope on buried section 5 due to a grade break in the middle of the culvert. I found multiple maps that disagreed on the path of buried section 1, which inhibited my ability to collect data outside of a rough estimation of its length.

Table 4. Data collected at each buried stream section within the Wilson Creek study area. Measurements were collected to characterize buried sections and predict potential salmonid passage.

<table>
<thead>
<tr>
<th>Buried Section</th>
<th>Span (m)</th>
<th>Slope (%)</th>
<th>Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unknown</td>
<td>Unknown</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>1.4</td>
<td>1.10%</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>-1.30%</td>
<td>14.8</td>
</tr>
<tr>
<td>4</td>
<td>1.4</td>
<td>-0.42%</td>
<td>24.4</td>
</tr>
<tr>
<td>5</td>
<td>1.4</td>
<td>Unknown</td>
<td>20</td>
</tr>
</tbody>
</table>
Five YOY and twenty-five adult/juvenile salmonids moved through buried sections of stream on 98 occasions. Most of this movement occurred in the upstream direction during October. Upstream movement occurred through 4 of the 5 buried sections and downstream movement occurred through all 5 buried sections. Adult/juvenile fish were documented moving through buried sections during each month of the study, while YOY

Figure 13. Photographs of the downstream end of buried sections 1-5 within the Wilson Creek Study area.
were only documented moving through buried sections during August, October and January. No salmonid moved upstream through the ~300 m buried section 1 (Figure 14).

**Figure 14.** The frequency and directionality of movement by PIT-tagged salmonids through buried sections of stream within the Wilson Creek study area. Buried section 1 appears to be a barrier to the upstream movement of salmonids.

**Movement**

Range was calculated using the furthest open segment downstream and upstream in which a fish was observed during the study. Movement ranged from 0 to 700 m while 50% of tagged salmonids covered a range of less than 66 m (Figure 15). It would be expected that larger salmonids would occupy a greater range due to their superior swimming capability to smaller YOY. The results of a Spearman Rank Correlation indicated a significant positive relationship between salmonid FL and range of movement but a weak predictive value (Figure 16, ρ =0.3532, df =93, p =0.0004). This weak predictive value may have been influence by the restricted movement of salmonids through buried section 1.
To examine the direction of movement for each fish and instances of site fidelity, I calculated the distance between their initial capture location and their final observed location. The spread of the data indicates that fish were able to move up and downstream, with an average movement of 16.5 m downstream. The maximum downstream movement by a salmonid was 601 m and the maximum upstream movement was 244 m. Of the 95 fish included in this analysis, 40% were found within 10 m of their original capture location at their final point of observation (Figure 17).

![Histogram of fish movement distances](image)

**Figure 15.** The range of movement of PIT-tagged salmonids within the Wilson Creek study area from June 10th through January 23rd (N = 95 Min = 0.0 Max = 700 Median = 65.0 Mean = 86.9).
Figure 16. The relationship between length and range of movement of PIT-tagged salmonids within the Wilson Creek study area. Spearman Rank Correlation indicated a significant positive correlation but low predictive value ($\rho = 0.3532$, df = 93, $p = 0.0004$). This was likely influenced by the 300 m buried section that prevent the upstream movement of salmonids.
**Figure 17.** The distance between first and last detection of PIT-tagged within the Wilson Creek study area. N = 95, Downstream Max = 601, Upstream Max = 244. Demonstrating that salmonids were able to move both up and downstream throughout most of the study area.
V

DISCUSSION

Influential papers by Walsh et al. 2005 and Wenger et al. 2009 reviewed literature on urban streams and addressed key research questions facing the field of urban stream ecology including, “How does urbanization affect movement of aquatic organisms and populations both within and beyond urban areas?”. These two studies have been cited by 1,633 papers with 1,063 mentioning fish. Out of these 1,063 papers, only 79 studied fish in urban streams, while just 4 studied the movement of fish. Additional searches over the past two years resulted in a handful of studies on the movement of fish in urban streams with only one focusing on salmonids.

To my knowledge, this is the first project to study the movement and habitat use of a naturally occurring population of salmonids in an urban stream. Using a combination of electrofishing, stationary antennas and a portable antenna, I successfully monitored two species of salmonids over a ~8-month period. Additionally, the presence of a restored section of stream surrounded by degraded stream sections enabled me to study salmonid habitat use and evaluate the benefit of restoring urban stream habitat. Documenting high densities of salmonids, spawning activity and an abundance of YOY brook trout demonstrates that Wilson Creek can sustain a salmonid population. However, the presence of a probable movement barrier suggests that there are significant challenges to the restoration of native salmonids in Wilson Creek.
Temperature and Growth

Stream temperature is a significant contributor to the growth and survival of all species of salmonids (Sullivan et al. 2000). Temperature requirements for salmonids are variable among species and locally adapted populations; however, all salmonids are generally characterized as obligatory cold-water species. It has been suggested that an annual maximum stream temperature below 26 °C is required for a stream to support salmonid populations (Sullivan et al. 2000). Within the study area, temperatures ranged from 0.45 - 21.14 °C, which fell within the temperature tolerance established for both brook trout and rainbow trout (Raleigh 1982; Raleigh et al. 1984). With adequate food, brook trout and rainbow trout growth ceases to occur when stream temperatures reach 20 °C and 23 °C respectively (Raleigh 1982; Raleigh et al. 1984). Maximum daily temperature in the study area occasionally exceeded 20 °C; however average daily stream temperatures never reached the growth cutoff for either species (Raleigh 1982; Raleigh et al. 1984). This data indicates that temperature in the study area met the needs of brook trout and rainbow trout.

Salmonid survival is closely associated with growth and the ability to successfully reproduce (Sullivan et al. 2000). Length data from YOY brook trout from 20 streams across the United States resulted in an average length of 80.6 mm at the end of their first year of life (Wydoski and Whitney 1979). YOY collected during the final capture event in Wilson Creek had an average FL of 125.9 mm. Average FL of YOY brook trout doubled from 62.9 mm on June 6th to the final capture event on January 23rd. Increases in average FL of older age classes of brook trout was not as significant, likely due to the allocation of resources for reproduction. Excluding YOY, brook trout collected during the final capture event exhibited
slender body cavities indicating spawning activity. It is likely that nutrient enrichment, that is commonly linked to urbanization, along with intensive agricultural practices upstream, sustained a substantial prey base for salmonids in Wilson Creek (Paul and Meyer 2001; Walsh et al. 2005). Suitable stream temperature and food supply likely allowed brook trout to achieve a high rate of growth which could benefit the survival of juvenile anadromous salmonids in Wilson Creek.

**Habitat Quality and Associations**

Over past decades, efforts to improve stream habitat through restoration have become commonplace. Stream restoration can improve conditions for aquatic organisms and restore natural ecological functions (Roni et al. 2008; Poplar-Jeffers et al. 2009; Pess et al. 2012; Roni et al. 2014; Monk 2015; Neale and Moffett 2016). However, attempts to evaluate the success of stream restoration projects are often inadequate, requiring well-defined goals and long-term monitoring (Roni et al. 2008; Roni et al. 2014). In an effort to evaluate habitat quality and the success of this restoration project, I used a variety of habitat metrics to compare the quality of habitat available to salmonids in each of the five open sections of stream.

Suitable habitat influences the abundance and persistence of salmonids in freshwater ecosystems (Raleigh 1982; McMahon 1983; Raleigh et al. 1984; Sullivan et al. 2000; Pess et al. 2012). Salmonids of all age classes were found within each open section, indicating that none of the habitat was degraded enough to prevent its use. However, descriptive habitat metrics demonstrated that habitat quality was highly variable within the five open sections of stream. Additionally, a chi-squared goodness-of-fit test indicated
that within a severely altered urban stream, the presence of adult/juvenile salmonids was significantly associated with pool habitat (Figure 10). Section 1 consistently received high ratings among habitat metrics and had the highest percentage of pool channel units (Table 3). The presence of quality fish habitat found in this section likely resulted in high densities of salmonids and diversity of fish species.

**Movement**

Individual salmonids may remain within a small home range, make intermediate movements, or travel great distances over their lifetime (Kahler et al. 2001; Mellina et al. 2005; Petty et al. 2005; Morrissey and Ferguson 2011; Kanno et al. 2014). This variability has generated debate in the scientific community about the predominate movement pattern of resident salmonids (Gerking 1959; Gowan, et al. 1994; Rodriguez 2002). However, much of this debate can be associated with variability between populations, stream systems, and inconsistencies or inadequacies between study designs (Gowan, et al. 1994). For that reason, it is essential to have similar study designs when attempting to compare the movement of two salmonid populations.

When designing the movement portion of this study, much of it was modeled after a recent study by Kanno et al. 2014, which monitored the movement of brook trout in a natural system. The study examined a resident population in a 3rd order tributary to the Connecticut River, in western Massachusetts. Using electrofishing and stationary antennas, Kanno et al 2014 made observations on the movement of brook trout based on 20 m segments of stream. After four years of data collection, 62% of recaptured brook trout moved 40 m or less between their first and last capture locations (Kanno et al. 2014).
Within their 1 km study area, the largest documented movement by a brook trout was 820 m. Peak activity of brook trout occurred during June, October and November (Kanno et al. 2014). This study provided a baseline of what could be expected if salmonids could move naturally in an urban stream.

The movement of salmonids in Wilson Creek was similar to the movement of brook trout observed by Kanno et al. 2014. Wilson Creek is a 3rd order stream and the study area was 710 m in length. Of the recaptured salmonids, 60% moved 40 m or less between first and last capture locations. The maximum distance traveled by an individual was 700 m and brook trout activity peaked during October. This data indicates that in Wilson Creek, PIT-tagged salmonids functioned in a comparable matter to what has been observed in a natural system.

**Movement Barriers**

Salmonids were documented moving up and down through 4 of the 5 buried sections in Wilson Creek. Movement by all age classes was documented during baseflow at 0.05 m$^3$/s and the maximum observed flow of 0.625 m$^3$/s. Despite the ability of salmonids to move through most of the study area, the data also suggest that one buried section of Wilson Creek impeded the movement of salmonids. Spawning season typically triggers upstream movement of salmonid populations and was documented through much of the study area (Morrissey and Ferguson 2011; Kanno et al. 2014). However, at no point were salmonids observed traveling upstream through the 300-m buried section of stream.

Previous research has also reported decreased density of salmonids and diversity of fish communities upstream compared to downstream of movement barriers (Burford et al.
A decline was observed above the 300 m section, with a density of 0.45 salmonids per meter in section 1 and 0.11 salmonids per meter in section 2. Additionally, 7 species of fish were found in section 1 with a Shannon diversity rating of 1.35. Comparatively, in section 2, only 3 species were documented with a Shannon diversity rating of 1.03. Other factors such as habitat quality can affect the density of salmonids and diversity of fish communities. However, the documented upstream decline of these metrics combined with the lack of upstream movement indicates that the 300 m buried section is likely a movement barrier.

**Anadromous Salmonids in Wilson Creek**

The goal of this study was to observe the movement and habitat use of salmonids to evaluate their potential reintroduction into urban streams. The reintroduction of anadromous salmonids has been discussed for Wilson Creek to aid in the recovery of steelhead trout and coho salmon in the Yakima basin (Hubble 2004; Conley et al. 2009). The results of this study indicate Wilson Creek can support a self-sustaining salmonid population; however, the unique life history of anadromous fish may hinder their recovery in this urban stream.

Data collected on resident salmonids in Wilson Creek suggest that juvenile coho salmon and steelhead trout could thrive in this urban system. Brook trout have similar habitat requirements to coho salmon which made non-native brook trout a quality research analog. Both species prefer streams with a 1-1 pool-to-riffle ratio and an abundance of cover (Raleigh 1982; McMahon 1983). Adults spawn during the fall with brook trout preferring stream temperatures of 4.5 – 10 °C and coho 4.4 – 9.4 °C for
spawning (Raleigh 1982; McMahon 1983). Coho require much larger substrate for spawning, however fertilized eggs of both species incubate for ~45 days in cold, silt free, well oxygenated gravel prior to hatching (Raleigh 1982; McMahon 1983). Optimal growth for brook trout occurs from 11 – 16 °C, while optimal growth for juvenile coho salmon occurs from 10 - 15 °C, with growth ceasing for both species at ~20 °C (Raleigh 1982; McMahon 1983). Similarities between brook trout and coho indicate that Wilson Creek could support juvenile coho. Likewise, the presence of rainbow trout in Wilson Creek indicates that the habitat requirements for juvenile steelhead trout can be met. Average daily stream temperatures from June through September fell within the optimal range for growth for juvenile steelhead of 11 – 18 °C during 101 of 115 days (Raleigh et al. 1984). This indicates that juvenile coho salmon and steelhead trout in Wilson Creek could expect to exhibit growth rates similar to those observed for YOY brook trout during this study. Growth rates comparable to brook trout in Wilson Creek could prove beneficial to the recovery of steelhead trout and coho salmon in the Yakima basin. Larger juvenile salmonids have been shown to have a competitive advantage over smaller salmonids, increasing their odds of survival (Abbott et al. 1985; Rhodes and Quinn 1998).

Despite favorable growth conditions and suitable habitat, significant issues associated with buried stream sections must be addressed before attempting to reestablish anadromous salmonids in Wilson Creek. A rough count of buried stream sections on the lower 25 km of Wilson Creek yielded over 60 structures, all representing potential barriers to the movement of salmonids. While data from this study indicate that low gradient culverts may not hinder the movement of salmonids, a single poorly designed culvert could completely block the upstream movement of salmonids.
Additionally, downstream of the study area a ~800 m buried section of Wilson Creek flows beneath sidewalks, roads, and buildings on its path through downtown Ellensburg. This buried section has been identified as the largest obstacle to the reintroduction of anadromous salmonids in Wilson Creek. The substantial resources needed to reroute or restore Wilson Creek to improve fish passage makes the reintroduction of anadromous salmonids to this stream unlikely in the near future.

However, the reintroduction of coho salmon and steelhead trout has been discussed for many urbanized streams within the upper Yakima basin including Wilson Creek, Reecer Creek, Mercer Creek, Whiskey Creek, Naneum Creek and Cherry Creek (Hubble 2004; Conley et al. 2009). Similar to Wilson Creek, the majority of these streams have issues related to connectivity, water quality, fine sediment inputs, invasive species, channelization, lack of LWD, degraded riparian areas, and altered stream flows. However, none of these streams have buried sections as large and complex as the 300 m and 800 m sections of Wilson Creek, potentially making these streams a higher priority for the reintroduction of anadromous salmonids.

**Salmonid Recovery in the Upper Yakima Basin**

Historic annual steelhead and coho returns to the upper Yakima basin have been estimated at over 20,000 and 110,000 respectively (Yakama Nation Fisheries 2014). In the 1980s annual steelhead returns to the Yakima basin dropped to around 1,000 while coho returns were virtually nonexistent (Yakama Nation Fisheries 2014). Through policy changes, supplementation, restoration, and the 2006 threatened listing of Middle Columbia River steelhead (includes Yakima River steelhead) under the Endangered Species Act (ESA)
these populations have rebounded (Conley et al. 2009; Yakama Nation Fisheries 2014). Steelhead returns have exceed 4,000 fish each year from 2009-2015, while coho have averaged returns of ~7,000 individuals over the past decade (Yakama Nation Fisheries 2014). Despite this success, the upper Yakima River wild steelhead are returning at well below sustainable levels and coho are mainly of hatchery origin (Yakama Nation Fisheries 2014). Further recovery of these species will require a concerted effort from a variety of stakeholders within the region.

Multiple agencies and interest groups have played a large role in the recovery of coho salmon and steelhead trout. It has been estimated that as of 2012, ~68% of the Yakima basin qualifies as functional steelhead habitat (Yakama Nation Fisheries 2014). By 2033, the goal is to increase that to ~90% (Yakama Nation Fisheries 2014). Coho salmon and steelhead trout often spawn in tributaries to large rivers. Spawning in tributaries increases genetic diversity through local adaptation and provides insurance against a natural disaster damaging the entire population (Crisafulli et al. 2005; Primmer et al. 2006; Waples et al. 2008; Pess et al. 2014). For these reasons, providing access to tributary habitat has been a priority for the recovery of both species.

It has been demonstrated both locally and throughout the Pacific Northwest that if salmonids are provided access to suitable habitat they will recolonize a system (Crisafulli et al. 2005; Pess et al. 2014; Monk 2015). Recently, fish passage barriers have been removed on two tributaries in the upper Yakima basin. In 2009, a movement barrier in the form of an irrigation dam was removed from lower Taneum Creek, providing salmonids access to 38 miles of historic habitat (Monk 2015). Steelhead quickly recolonized the system with yearly returns of 29 - 66 adults from 2010 – 2014, while adult coho have also
been observed in Taneum Creek (Monk 2015). Additionally, over the past 15 years, multiple agencies have worked to provide salmonids access to Manastash Creek (Bureau of Reclamation 2013; Buhr 2016). In the winter of 2016 the final fish passage barrier was removed, providing anadromous salmonids access to 25 miles of quality habitat (Bureau of Reclamation 2013; Buhr 2016). Five months later, a female steelhead was documented returning to spawn in Manastash Creek for the first time in over a century (Buhr 2016, PITAGIS 2017).

The instinct of salmonids to recolonize habitat can lead them to even the most degraded stream system. For much of the year, large buried sections of Wilson Creek are likely barriers to the upstream movement salmonids. However, on November 14th, 2016, during a period of elevated stream flow, the bottom of site stationary antenna in Wilson Creek recorded a PIT-tag from a 133 mm wild juvenile steelhead. The fish was captured and released in August 2016 by the Washington State Department of Fish and Wildlife in the Teanaway River, a major tributary to the Yakima River (Personal communication with Ryan Steele 2017).

To reach this antenna, the juvenile steelhead likely navigated ~14 km of urban stream through multiple buried sections including ~800 m of stream running beneath the city of Ellensburg. This juvenile steelhead likely represents the first documented upstream movement of a salmonid through the largest buried section of Wilson Creek (Personal communication with James and Temple 2017). On March 20th 2017, the same PIT-tagged juvenile steelhead was encountered in the lower Yakima River, at the juvenile salmonid bypass facility on Prosser Diversion Dam (PITAGIS 2017). It’s likely that this fish overwintered in Wilson Creek before beginning its seaward migration the following spring. The
documentation of an ESA listed juvenile anadromous salmonid using the most inaccessible urban stream in Kittitas County is encouraging for their future recovery to the region’s urban systems.

**Management Implications**

The incentive to improve urban streams in the upper Yakima basin extends beyond anadromous salmonid recovery. Urbanization has increased the frequency and severity of flood events (Hollis 1975). In Kittitas County, land use practices and poorly designed infrastructure, including buried sections of stream, are often responsible for the damage of public and private lands (Kittitas County Regional Planning Office 1973; Kaatz 1996; Johnson et al. 2011). Additionally, issues associated with climate change, irrigation, agriculture, pollution, and population growth have created a need to alter current water management to meet future demands. Restoration and the removal of fish passage barriers are expensive and will involve a variety of stakeholders from the agricultural, industrial, and conservation communities.

In an effort to direct future projects to improve water quality, reduce flooding, and enhance irrigation systems, the Naneum, Wilson, and Cherry Creek Assessment was initiated in 2014 to evaluate the current condition of urbanized streams that flow through Kittitas County (Kittitas County 2014). Additionally, this assessment was developed to address “limiting factors to recovery and enhancement of steelhead, salmon, and other aquatic species within the study watersheds” (Kittitas County 2014). Culvert assessments, temperature monitoring and hydrological surveys will help local agencies prioritize the removal of fish passage barriers and identify locations where restoration would be most
feasible and beneficial. Thus, improving urban streams to meet the demands of an expanding human population can also benefit the recovery of anadromous salmonids.

The results of this study demonstrated that despite a large movement barrier, salmonids exhibited movement patterns and spawning activity similar to what has been documented in a natural system. YOY, juvenile, and adult salmonids were able to successfully navigate buried stream sections through low gradient culverts of 15 - 30 m in length. A variety of habitat metrics also indicated that habitat restoration can be successful in an urban stream resulting in increased salmonid densities and diversity of fishes. Additionally, stream temperatures and growth rates revealed that juvenile salmonids could experience elevated growth, which could benefit their survival. This indicates that by prioritizing the removal of major fish barriers, anadromous salmonids could use urbanized streams and access high quality headwater habitat sooner than previously expected, aiding in the recovery of anadromous salmonids in the Yakima basin.
REFERENCES


Kittitas County. 2014. Naneum, Wilson, and Cherry Creek Watershed Assessment Project Scope of Work.


**Figure 18.** LWD located in open sections of stream within the Wilson Creek study area. All LWD pieces had a minimum length ≥ 1 m and a diameter ≥ 10 cm

**Figure 19.** Average fish cover for each open section of stream within the Wilson Creek study area. Fish cover elements included woody debris, overhanging vegetation, aquatic vegetation and artificial fish cover
Figure 20. Substrate composition estimations for each open section of stream within the Wilson Creek study area

Figure 21. Percent canopy cover for each open section of stream within the Wilson Creek study area
Figure 22. Sinuosity rating for each section of open stream within the Wilson Creek study area; higher sinuosity ratings indicates greater channel complexity.

Figure 23. The percent of channel unit type occurring in each section of open stream within the Wilson Creek study area.